Chapter 1

Acronyms and Abbreviations

AGW Acoustic Gravity Wave

AWG(N) Additive White Gaussian (Noise)

ARPA Advanced Research Projects Agency

BSS Backscatter Sounding by frequency Sweep

CIT Coherent Integration Time

CNIT National Inter-universitary Consortium for the Telecommunications

CNR Clutter-to-Noise Ratio

CODAR COastal raDAR

CR Coordinate Registration

DEM Digital Elevation Models

DET Department of Electronic and Telecommunications (UniFI)

DID Digital Ionogram Database

DoD Department of Defence

dr down range

DSTO (Australian) Defence Science and Technology Organization

DTED Digital Terrain Elevation Data

ECRS East Coast Radar System (USA)

EEZ Exclusive Economic Zone

ELS Sounding by ELevation Scanning

EM Electro-Magnetic

FBRA Forward-Based Receiver Augmentation (for OTHR)

FMCW Frequency Modulated Continuous Wave

FMS Frequency Management System

GCC Ground Coordinate Correction

GPS Global Positioning System

GW Ground Wave

HAARP High Frequency Active Auroral Research Program

HF High Frequency

HFSWR HF Surface-Wave Radar

INGV (Italian) National Institute of Geophysics and Volcanology

IOOS Integrated Ocean Observing System (NOAA)

IPS Ionospheric Prediction Service

IRI International Reference Ionospheric (model)

ITU-(R) International Telecommunication Union - (Recommendation)

JORN Jindalee Operational Radar Network

LOS Line Of Sight

LPI Low Probability of Intercept

LUF Lowest Usable Frequency

MADRE MAgnetic-Drum Radar Equipment

MQP(IM) Multi Quasi Parabolic (Ionospheric Model)

MRL Microwave & Radiation Laboratory (University of Pisa)

MUF Maximum usable Frequency

NOAA (US) National Oceanic and Atmospheric Administration

NRCS Normalized Radar Cross Section

NRL (US) Naval Research Laboratory

OIS Oblique Incidence Sounder

ONERA (FR) Office National d'Etudes et de Recherches Aerospatiales

OTH(B)R Over The Horizon (Backscatter) Radar

PNAV Precise NAVigation

PRF Pulse Repetition Frequency

QCS Quasi Cubic Segmented (ionospheric model)

QPM Quasi Parabolic Model

QPS Quasi Parabolic Segmented (ionospheric model)

QVI Quasi Vertical Ionogram (or Ionosonde)

QVIS Quasi Vertical Incidence Sounder

R&D Research & Development

RAF Royal Air Force (UK)

RASS National Laboratory on Radar and Surveillance Systems

RCS Radar Cross Section

ROTHR Relocatable Over-The-Horizon Radar

RSGB Radio Society of Great Britain

RT RayTracing

RTIM Real Time Ionospheric Model

Rx Receiver

SAR Synthetic Aperture Radar *or alternatively* Search And Rescue

SCR Signal to Clutter Ratio

SID Sudden Ionospheric Disturbances

SLBM Sea-Land Binary Mask

SLMI Sea-Land Fractional Mask

SLTI Sea-Land Transition Identification

SNR Signal to Noise Ratio

sr slant range

SRI Stanford Research Institute

SSN Sun Spot Number

STUDIO Systme de Traitement Universel de Diagnostic IOnosphriques

Super-DARN Super Dual Auroral Radar Network

SW Sky Wave (see also “GW”)

T/M Terra/Mare

TDM Time Division Multiplexing

TID Traveling Ionospheric Disturbances

TOA Time Of Arrival

TSI Total Solar Irradiation

Tx Transmitter

UniFI University of Florence

USAF United States Air Force

UTC Universal Time Coordinated

VIS Vertical Incidence Sounder

WARF Wide Aperture Research Facility

WCRS West Coast Radar System (USA)

WSBI Wide-Sweep Backscatter Ionogram

Chapter 2

Introduction

Despite it is based on a well known technology, the Over The Horizon Sky Wave Radar (OTHR-SW), developed during World War II and largely employed during the “Cold War”, is attracting today much interest, thanks to the great steps forward in the signal processing and data storage techniques made in the last years. The OTHR systems is an HF-band sensors that, via surface propagation (Ground-Wave) or ionospheric reflection (Sky-Wave), covers an area that is located well beyond the horizon line, natural operational limit for all of the ground-based microwave radar.

While a Ground-Wave system exploits the surface propagation of HF signals reaching areas located up to about 700 kilometers from the radar, the Sky-Wave systems are characterized by a parabolic propagation path that allows them to extend their ground-range up to 3000 kilometers. The main strength of the OTHR-SW is represented exactly by the fact that it is the only ground-based sensor with a surveillance area comparable in surface with that of satellite-constellations or airborne-radar-networks. This feature is achieved by exploiting the propagation characteristics of the Ionosphere that, although absorbing and refracting in part the HF signal, reflects the most of it toward the ground and, with a similar path, redirects again the radar echo toward the OTHR-SW receiver. This is what is referred to as a ”‘single hop”’ since the signal and the echo expertise both a single interaction with the Ionosphere. Transmission based on multiple ionospheric hops are also possible, but they are not taken into account in the present work because they imply an excessive attenuation of the signals.

Nevertheless, the employment of the Ionosphere as part of the propagation channel implies a substantial uncertainty in the actual ray path. In fact, the

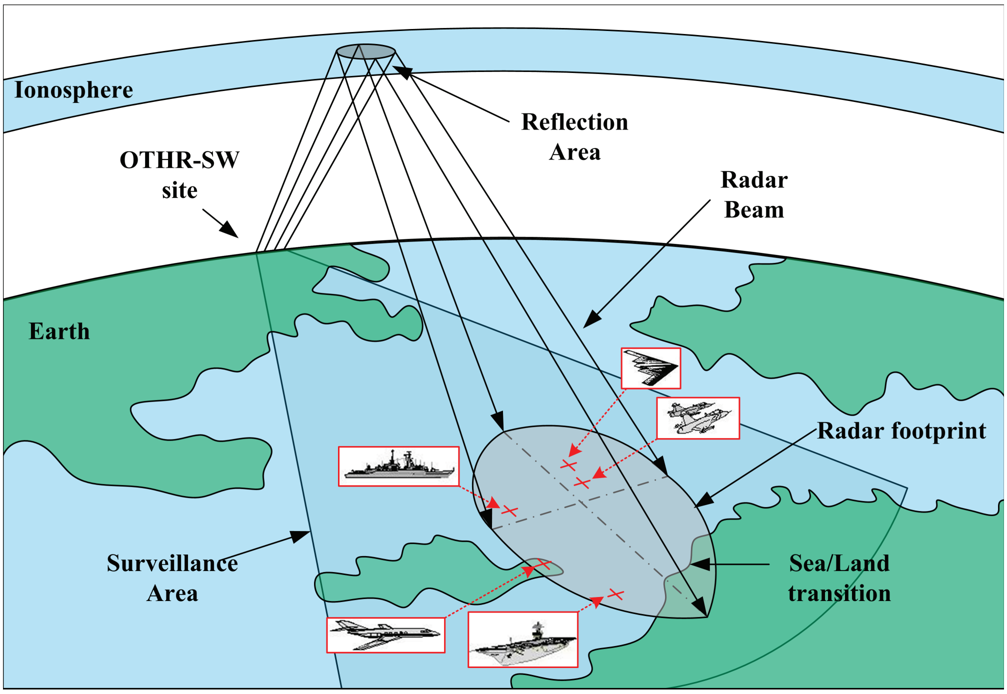

Figure 2.1. *Simplified sketch of the principle of operation of an OTHR-SW system.*

non-homogeneous structure and time-dependent behaviour of the Ionosphere has important repercussions in OTHR-SW Coordinate Registration (CR) procedures of current common use. The consequent uncertainty propagates to every radar measurement and the estimated position of an eventually detected target can result heavily inaccurate. So far, several different approaches to the CR task for OTHR-SW systems have been developed. Most of them require external sources of information arranged within the surveillance area, such as ionosonde networks (section 5.1), beacons and/or transponders (sec. 5.2), passive receivers (sec. 5.5), additional radar systems (sec. 5.4), etc. Nevertheless often the employment of these methods in an operative radar context is limited by at least one of the following factors: the construction/maintenance costs growth due to the introduction of multiple external systems; the need to arrange those systems within the surveillance area (generally a restricted access zone); the sporadic nature of additional information availability.

The OTHR-SW real time CR approach developed during the presented research is referred to as *"'Sea-Land Transition Identification"'* (SLTI) method. Differently from the other approaches, the SLTI method does not ask for any information source external to the radar, but exploits the a priori knowledge of the geo-morphological structure of the surveillance area in order to geo-reference

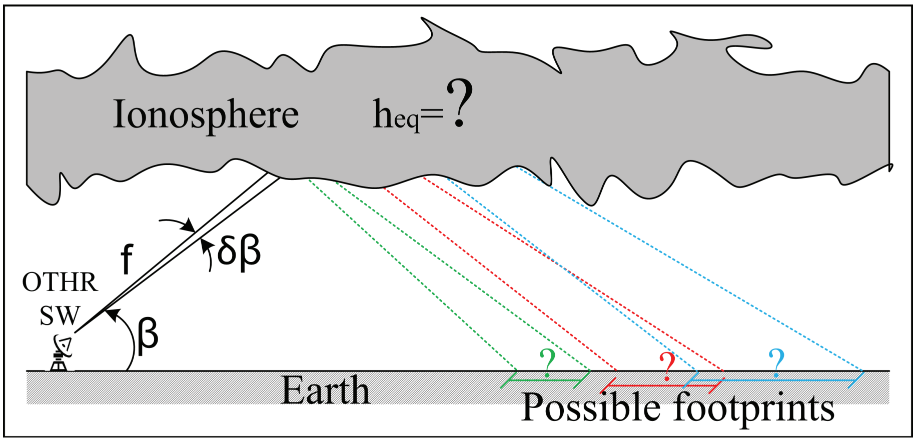

Figure 2.2. *Need of a CR process to determine the real signal path in OTHR-SW applications.*

in real time the received echoes. In fact, although OTHR transmission channel is non-homogeneous and time-dependent, therefore extremely hard to model (eventually requiring continuous ionospheric soundings), the surveillance area geo-morphological structure is a constant data and can be easily employed as static geographic reference for a given OTHR system.
The SLTI method is based on the cross-correlation between the received echo and the reference signal derived from a surface clutter-mask based on geographic information and on the operational radar antenna parameters and pointing direction.

The thesis begins with a global introduction about the OTHR systems, that ranges from some historical notes to the actual employment of the system nowadays, with particular attention on sky-wave apparatus. Then a general description of the Ionospheric propagation channel is given, together with the model and characterization parameters for the Ionosphere that will be part of the simulated OTHR-SW scenario implemented to demonstrate the application of the SLTI algorithm. The state of the art for what concerns the *Coordinate Registration* procedures is then presented and commented in order to explain the reason of the need for a brand new approach that overcomes the most common problematic. Hence the SLTI method is presented and described in depth, together with the requirements for its application in a simulated OTHR-SW scenario. The main model hypothesis and assumptions are commented and justified. At this stage all the information on the simulated OTHR-SW scenario and on the proposed geo-referencing method (SLTI procedure) are given. In order to better understand the application of the SLTI procedure two example are provided, concerning respectively the *Coordinate Registration* task and the *Ionospheric Probing* task. In fact, besides its employment for the real-time CR of the received OTHR-SW echo, the SLTI method is suitable also for the assessment of several Ionospheric parameters and it can be employed for a periodical update of a given Ionospheric model. Finally we provide the main considerations on the proposed method and on its application in a real OTHR-SW system and we present some further developments and improvements of the proposed SLTI procedure and the developed model of the OTHR-SW scenario.